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Robert Cordova
ADH: Engineering - Arkansas Department of Health

Bobby Makin
ADH: Engineering - Arkansas Department of Health

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Robert Cordova and Bobby Makin
Department of Health
Division of Engineering
4815 West Markham (Slot 37)
Little Rock, AR 72205

Abstract

The Wellhead Protection (WHP) program was authorized by the 1986 Amendments to the Safe Drinking Water Act. The Arkansas Department of Health in July, 1986, was designated by Governor Clinton to be the lead agency in carrying out the WHP program. The program is designed to protect the ground-water resource tapped by public water-supply wells from contaminants which are injurious to the public health. It is the first formal attempt by the federal government in its environmental protection role to prevent contamination from taking place, in contrast to costly clean-up or remediation programs. Among its several requirements, the program includes: 1) delineating a wellhead protection area for each well or wellfield; 2) identifying all potential man-made sources of contaminants injurious to public health within each WHP area; and 3) developing outreach activities for increasing public awareness. Some major accomplishments since program start-up in 1991 include delineations for more than 200 wells and implementation of the WHP program for more than 50 public water systems. Since the actual implementation of the program, experience and investigation have shown that several methods of delineation are usable in Arkansas. Some methods are most pertinent to aquifers in the Coastal Plain and others to aquifers in the Interior Highlands.

Introduction

The Wellhead Protection program is part of the 1986 Amendments to the Safe Drinking Water Act. The program is designed to protect the ground-water resource tapped by public water-supply wells from contaminants which are injurious to the public health. The program is the first formal attempt by the federal government in its environmental protection role to prevent contamination from taking place, in contrast to costly clean-up or remediation programs. The WHP program applies to existing and to future public water-supply wells.

The Arkansas Department of Health in July, 1986, was designated by Governor Clinton to be the lead agency in carrying out the WHP program. As lead agency, ADH administers the program by guiding its development, coordinating the wellhead protection activities with other state agencies and organizations, providing the technical expertise and assistance required to implement the local programs, developing a management framework, and by encouraging the public to actively participate in the implementation of the program.

A question that may be reasonably asked is why is such a program needed. Three good reasons answer this question:

1.) Arkansas uses a lot of ground water: for all purposes, 17,820,348 cubic meters (4,708 million gallons) per day based on 1990 figures. To put such a large number in perspective, Arkansas' usage is about 25 percent of that of California, about 55 percent of that of Texas, and Arkansas is 7th among all the states in ground-water usage. The fact that such an enormous amount of ground water is pumped from wells in Arkansas tells us clearly that contamination of the ground-water reservoir is an enormous possibility. The state's aquifers are literally pin cushions pricked by thousands if not tens of thousands of wells (water, gas, and oil), many of which are abandoned or unused. Usage for public supply is only about 2.5 percent of the total usage in Arkansas, or about 450,226 cubic meters (120 million gallons) per day. However, this amount supplies about 500 public water systems and about 40 percent of the state's population. From these numbers, there is no doubt that Arkansas relies heavily on its ground-water resource for public as well as other supplies.

2.) There are numerous potential sources of contamination. They may be divided into three main categories. First, the potential sources that are on the land surface including such things as animal feed lots and above-ground chemical storage tanks. Second, potential sources that are located in the ground, but above the water table, like septic tanks and underground petroleum storage tanks. Thirdly, the potential sources that are located in the ground below the water table including mainly wells and mines. Wells, both water and oil, are one of the most common potential sources in Arkansas, especially old, abandoned wells that may have casings perforated secondarily by corrosion and cement sheaths cracked by subsidence.

3.) There are numerous chemicals dangerous to health that may infiltrate to the water table if they are not managed or used properly. For example, the U.S. EPA's (Environmental Protection Agency, 1993) National Primary Drinking Water Standards list includes more than 70 organic and inorganic chemicals like arsenic, mercury, benzene, ethylbenzene, toluene, and vinyl chloride, to name a few familiar ones. A much longer list is the U.S. EPA's (1994) list of hazardous substances developed for the CERCLA program which contains more than 1,000 chemicals.

Discussion

The WHP program requires that each public water-supply well or wellfield be protected by an environmentally managed area that surrounds a well or wellfield on the land surface and also in the subsurface. This three dimensional zone is called the Wellhead Protection Area (WHPA). The longest dimension of the WHPA at the land surface may be measured in hundreds or thousands of feet. The WHPA's size and shape depend on hydrogeologic, economic, legal, and political factors. The WHPA should be determined scientifically by a ground-water specialist using site specific hydrogeologic data. The philosophy behind the size of the WHPA is that it should be small enough to be effectively managed, but also large enough to be environmentally useful.

The purpose of delineating a Wellhead Protection Area around a public-supply well is to protect the aquifer supplying the well from contamination. The part of the aquifer that supplies the well is termed the zone of contribution (ZOC) and within this zone is the zone of influence (ZOI) of the pumping well. The size and shape of the ZOC are limited primarily by an aquifer's hydrogeologic boundaries, whereas, the size and shape of the ZOI are limited primarily by an aquifer's hydraulic properties. Therefore, the ZOC may be considerably larger than the ZOI and is most likely to extend beyond the legal jurisdiction of the well's owner. That is, the ZOC may extend into adjacent counties, states, and drainage basins. The sheer size coupled with the jurisdictional ramifications faced by a well owner trying to develop a wellhead protection program based on the ZOC may present problems that are exceedingly impracticable to surmount. The ZOI may also be extensive, especially in artesian aquifers. The ZOI is essentially, but not exactly coincident with the cone of depression caused by pumping. Some cones of depression in the Arkansas part of the Coastal Plain extend over a considerable part of a county or even into adjacent counties. Many, and perhaps most, extend out of the jurisdictional boundaries of the communities owning the wells. Considering the possible large size of a ZOI or ZOC and also considering the need for effective management (economically, legally, and politically), the goal in Arkansas is to delineate WHPA's that are manageable from a strongly utilitarian and practicable standpoint.

Since the actual implementation of the Arkansas program in 1991, experience and investigation by the program hydrogeologist has shown that several methods of delineation are usable in Arkansas:

- Arbitrary fixed radius
- Volumetric
- Hydrogeologic mapping and hydrologic budget combined
- Mathematical flow equation

The method of delineation that may be chosen for a specific well depends on the availability of site-specific hydrogeologic and hydraulic data. Driller's logs, geologic maps and geologic cross sections are relatively abundant and easily obtainable and therefore, are the main sources of basic information for determining the geologic composition and geometry of the aquifer. Logs are obtainable from the files of the public water systems, drilling companies, the state's Geological Commission and the Water Well Construction Commission. Aquifer hydraulic data by comparison are not abundant or easily obtainable. The U.S. Geological Survey's reports and files are the main sources of this kind of information because it has conducted aquifer tests and hydrogeological investigations in many parts of the state. However, most aquifer-test data are not site specific to public-supply wells, so generalizations and extrapolations from test sites have to be made. The large degree of heterogeneity of the consolidated and unconsolidated rocks in Arkansas makes it largely untenable hydrogeologically to extrapolate from well to well, especially if the distance between wells is large. Extrapolation may easily result in significant errors in computing local ground-water conditions and therefore in WHPA delineation. The specific capacity test generally conducted by the water-well driller is usable as a source of hydraulic data but is limited in its hydraulic applications. In summary, the most prudent approach to delineating a WHPA is to choose the simplest method involving the smallest number of estimated or extrapolated quantities.

The arbitrary fixed radius method relies on rough judgement and not on science to determine the size and shape of the WHPA. The method is not used extensively in Arkansas, but is used where one of the scientific methods is not viable. The method is most applicable to aquifers in the Interior Highlands because of the various limitations put on standard hydrologic analytical techniques by consolidated-rock terranes comprising the Highlands.

The volumetric method uses a modified formula for the volume of a cylinder to calculate the radius of any WHPA, viz:

$$\text{Volume} = Qt = \Pi r^2 hn$$

where, Q = pumping rate of well or well field
t = travel time to well from boundary of WHPA
Π = pi = 3.1416
r = radius of circular WHPA
h = thickness of aquifer or water producing zone
n = effective porosity of the aquifer

This method is most tenable for the unconsolidated aquifers of the Coastal Plain and of alluvial stream valleys of the Interior Highlands. The hydraulic factor of porosity may be estimated with a fair degree of certainty because of the large amount of laboratory determinations that have been made on sands and gravels, the main aquifer materials. The results of such determinations have been published in reports of the U.S. Geological Survey and are the primary source used for WHPA calculations in Arkansas (Morris and Johnson, 1967). The other factors, aquifer thickness and pumping rate, are relatively easy to obtain and are fairly accurate. Aquifer thickness may be determined from a driller's log or from a geologic cross-section based on subsurface investigations by federal or state agencies. Pumping rates may be obtained from the local water department. Many rates are measured by in-line, total-flow meters but many are design rates, which may be somewhat different from the measured rates.

The method based on hydrogeologic mapping combined with a hydrologic budget is used mainly for determining the boundary of a WHPA in the consolidated-rock terrane of the Interior Highlands. This method consists of two steps. The first includes mapping the surface-water and ground-water flow boundaries of the smallest drainage basin containing the well or wellfield. Mapping may be accomplished by the use of topographic maps and geologic maps. The second step includes the determination of a simplified hydrologic budget for the basin. The determination makes the assumptions (1) that the basin is a self-contained hydrologic unit, that is, precipitation equals or balances losses by evapotranspiration, and by outflow of runoff (ground water and surface water), and (2) that there is no long-term change of storage. If the basinal outflow is significantly larger than the inflow generated by precipitation, or if the well-discharge to runoff ratio is too large, it is concluded that the basin supplying the outflow is actually larger than the one initially mapped. In this case, the boundaries are subsequently changed to incorporate a larger basin in which inflow balances outflow, and runoff significantly exceeds well discharge. It should be noted that the numbers comprising this simplified budget are generally rough approximations so that rough approximate balances are all that are expected.

The mathematical flow equation used in Arkansas is the Theis nonequilibrium equation. This equation is commonly used in ground water flow problems and is discussed in textbooks and publications on ground-water hydraulics or on the theory of aquifer tests (Ferris et al., 1962; Lohman, 1972). This technique is used in the parts of Arkansas where the aquifers are in unconsolidated rocks, such as in the Coastal Plain. The Theis equation requires the determination of an aquifer's hydraulic properties. These properties have been mainly determined by the hydrological interpretation of the driller's water well performance test and the driller's log because of the general lack of aquifer-test determined properties.

Conclusions

The purpose of the WHP program is to protect the ground-water resource from contamination, in contrast to cleaning up the water after contamination. The philosophy now is to do everything possible to protect this resource from contamination. Cleaning up contaminated ground water has been found to be extremely costly and in many cases not possible because of the nature of the contaminating substances. The upshot of the cleanup experience nationwide is that protection practices must be put in place to reduce the risk if not prevent contamination from occurring in the first place.

The U.S. Environmental Protection Agency says that the average cost of a Superfund Site cleanup is about $25 million nationally. In Arkansas, sites with state financial involvement are costing about $5 million to $18 million to remediate. The state's involvement in developing the Wellhead Protection program, by comparison, is only about 1 percent of the smallest of these costs. Also, upfront initial costs of implementation of the program are nil or negligible. What better solution to protecting the ground-water resource than to adopt a penny-pincher's delight like the Wellhead Protection program.

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